BLADES AND BLADE-SUBSTITUTES IN POTATO HARVESTERS TO REDUCE SPILL-OUT LOSSES

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Growth Through Agricultural Progress

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Potato harvesting is rapidly becoming mechanized. It is estimated that there are more than 5,000 mechanical potato harvesters and more than 30,000 potato diggers in the United States. Approximately 1,200 of the mechanical harvesters are in the Red River Valley of North Dakota and Minnesota.

The harvesters and diggers are equipped with blades of assorted designs. Each design is presumably adapted to some specific type of soil or field condition. Growers have spent much money and time trying different styles of blades to find the one best adapted to their individual situation. Also, manufacturers have devoted much effort and expense in improving blade designs and increasing the number of options to meet various harvesting conditions. However, in spite of these efforts, digger and harvester blade performance has been persistently deficient or unsatisfactory under many harvesting conditions. The main difficulties are spill-out losses and lost operating time for cleaning off clogged blades.

Spill-out losses can reduce growers' net profits substantially. A large percentage of tubers lost in this way are below the surface and not visible after the machine has passed.

Because of great variability from field to field and from season to season, in both incidence and rate of spill-out losses, it is difficult to estimate accurately the total loss. Measurements indicate that spill-out losses with standard blade equipment range from 2 to 15 cwt. per acre. Under unusually adverse conditions losses have reached 30 cwt. per acre and may average 20 cwt. per acre for a period of several days or for an entire field.

During the most favorable half of a normal season a loss rate of 4 cwt. per acre would probably be representative, and during the less favorable half, 9 cwt. per acre. If 60 percent of the crop is harvested during more favorable conditions and 40 percent during less favorable conditions, and if these figures are applied to the 189,000 acres harvested in the Red River Valley (1960 crop), total spill-out losses under average conditions might be about 1-1/8 million cwt. Use of better adapted blades or blade substitutes to reduce spill-out and provide more trouble-free operation could achieve savings of more than a million dollars a year in this one area.

In seasons of generally adverse harvesting conditions such as occurred in 1957, the potential savings in crop and lost operating time could easily total from 2 to 3 million dollars.

Spill-out has been most persistent, and quantitatively most serious, in soils high in organic content and low in volume weight.

Mineral soils with low cohesive properties when dry may also become troublesome through stickiness when wet.

Engineers of the U.S. Department of Agriculture recognized spill-out problems shortly after potato harvesting research was started in 1948. As early as 1950 some of the contributory causes were identified. Rotary rod blade-substitutes were proposed by USDA engineers before adequate rod weeder components were available commercially. In 1955, with the cooperation of a farm equipment manufacturer, rotary rod blade-substitutes were installed experimentally in a two-row digger and proved practical in the first field tests as a substitute for a conventional digger blade. Since 1955, further tests have been made to improve the design of rotary rods and related blade-substitutes or blunt-nosed shares and to determine their operating characteristics, range of adaptability, and advantages and disadvantages. The rotary rod units have been developed in both driven and undriven styles and are now called rotary rod shares (driven) or roller shares (undriven). The success of the 1955 field tests and the work since have attracted

considerable interest among growers and manufacturers.

The purpose of this report is to summarize the results of various aspects of the study of blades and blade-substitutes (particularly rotary rods) as related to spill-out losses and to describe some of the developments that have proved practical and most satisfactory where spill-out has been a problem.

NORMAL BLADE FUNCTIONS

The blade[1] or blade-substitute may have both operational and structural functions. It has five operational functions of importance:

(1) It should excavate or loosen and lift the soil mass containing the tubers.

(2) It should sever roots (potato or weed roots, or sometimes even a sod layer) and exert a pulling action at a depth adequate to assure satisfactory tuber recovery.[2]

(3) Where required, it should exert similar action on buried fibrous remains of a previous crop, for example, alfalfa roots.

(4) It should gently lift soil and tubers with continuous, even delivery onto the primary apron.

(5) It should provide frontal protection against buried obstacles that might damage primary apron links.

Crushing action on the lower portion of the lifted soil mass is sometimes a desirable and feasible function.

In certain machine designs the blade has three structural functions:

(1) A one-piece blade may serve as a spacer strut between apron side-frame members.

(2) By attaching the blade with two bolts at each side or welding it into a small subframe it may serve as a diagonal bracing member.

(3) It can contribute to torsional frame strength or rigidity either with or without the additional strength of a flat front cross member to which it is bolted.

Rotating rod blade-substitutes (roller shares) can perform all the necessary operational functions. It is impractical to make them serve the structural functions. Structural adequacy at the front of the primary apron frame must therefore be provided both for these and for two-piece open-center blades. This has been done satisfactorily in experimental units and in commercial designs by placing a tubular cross member approximately 8 inches to the rear of the front apron idler rollers (center-to-center measurement).

WHY SPILL-OUT OCCURS

To determine why spill-out occurs, the mechanical movement of the soil and potatoes as the hill is lifted by a blade, bar, or rod share and placed on the primary apron has been observed. An analysis of these observations has lead to the following theory or explanation:

As the blade or share advances in a horizontal plane slightly below the deepest potatoes, the soil is crumbled and disturbed ahead and upward above the leading edge of the share at a forward sloping angle of about 45°. The action is similar to that produced by plows and other tillage tools.

The hill or ridge of soil is crumbled or crushed and slumps so that it tends to lose height at the middle of its cross section and to gain depth at the sides. With the digger or harvester, it thus becomes flattened to a thick ribbon of loosened material flowing onto the primary apron. The cross section of a hill thus disturbed is transformed from a trapezoidal shape to one

[1]The blade of diggers and harvesters is known in various localities by other names: share, shovel, spud, or lay. The size and shape of blades vary widely. The general shape may be described as flat, longitudinally concaved (with the forward edge more nearly horizontal than the rear edge), or laterally concaved (so that the cross section of the ribbon of soil as it passes over the blade is rounded on its lower side). Warped or compound curved shapes have also been used but are not common.

The term "ribbon" is used to designate the flowing mixture of soil, potatoes, clods, stones, vines, and other material carried on the aprons or conveyors of potato equipment. The term "ribbon zone" is that space ahead of the blade occupied by the soil and potatoes about to be lifted.

[2]Loss of an occasional odd tuber located at an excessive depth may be expected. Operating at an excessive depth in order to save a few deep-set tubers may be uneconomical.

more nearly rectangular. In this action many tubers move laterally before they are securely on the apron. Studies of the location of undisturbed tubers in the hill, made by very careful digging by hand, have shown that they are practically all well within the path of 24-inch and 26-inch digger aprons and that 97 percent or more are generally within a band only 16 inches wide.

Hawkins[3] reported a study of five varieties in England (20 plants each variety) which showed that "the whole crop is contained in an area 16-1/2" wide with its base 2-1/4" below the original seed potatoes."

French and Glaves,[4] studying three varieties of potatoes in North Dakota, found that 98 percent or more of Pontiac and Kennebec varieties were within a band 16 inches wide and more than 97 percent of the Norland variety were within a 16-inch band.

Blades with long points and a large soil contact area and blades that are not scouring freely disturb the hill farther ahead of the primary apron and contribute to lateral movement and spill-out of tubers before they reach the primary apron. Soil pushing in a sluggishly active hump slightly ahead of the share is a reliable sign indicating unseen spill-out of tubers to an experienced operator. When the soil is flowing smoothly and freely onto the front of the primary apron, well centered with the row, the operator can be reasonably sure that there is little or no spill-out of tubers.

Two possible approaches to the reduction of spill-out were obvious. Retainer plates or forward extension of the apron side plates were helpful in dry soil but entirely unsatisfactory in heavy or sticky soils. More helpful were changes that reduced soil contact area, improved soil scouring, and minimized the distance of soil disturbance ahead of the apron, particularly at the center of the hill. The most satisfactory overall solution to date has been a combination of the two, described later in this publication.

FACTORS AFFECTING SPILL-OUT

Factors in spill-out losses can be classified as follows:

1. Soil type and condition.
2. Varietal factors.
3. Blade condition and adjustment.
4. Inadequate primary apron seed.
5. Excessive undersweep or "boiling."
6. General machine design.

Soil.--The physical characteristics of some soils, especially at certain moisture levels, make them prone to scouring troubles with digger blades as they are with moldboard plows, cultivator shovels, and other common tillage machines. The nonscouring characteristics of a soil cannot be changed readily. Very loose soils may not develop enough pressure to make the soil slide over the usual blade area. Compaction and irrigation can temporarily modify the scouring characteristics (or qualities) but might not always be practical for reducing spill-out.

Good soil management practices, good tillage practices, a good cropping program, and building up the organic-matter content of the soil--all improve tilth and increase the looseness of the soil. This contributes to higher tuber yields, but it adds to the scouring problem and tends to increase spill-out losses.

Growers and others have observed that spill-out in a field is often greatest where yield is highest. Conditions favorable to maximum yields increase spill-out.

Varietal Factors.--Varietal factors that contribute to spill-out losses include: tenacity of attachment of tubers to stolons, tuber shape, and location of tubers in the hill. Clinging tubers may be carried onto the primary aprons in unbroken clusters. Round, detached or weakly attached tubers move laterally more freely when disturbed by the approaching share element. Wide-set and shallow-covered tubers are easily lost to the sides. Concentration or distribution of the tuber set may be a factor.

Blade Condition and Adjustment.--Even though blades of the best adapted design (shape and size) are used, the blades should (1) be operated at an angle favorable for scouring, (2) have a smooth, well-polished surface, (3) be operated at a depth to produce soil pressure adequate to give scouring if possible, and (4) be kept sharp enough to sever fibrous material encountered (or blunt edged and well rounded

[3] Hawkins, J. C. The design of potato harvesters. Jour. Agr. Engin. Res. 2: 14-24. 1957.

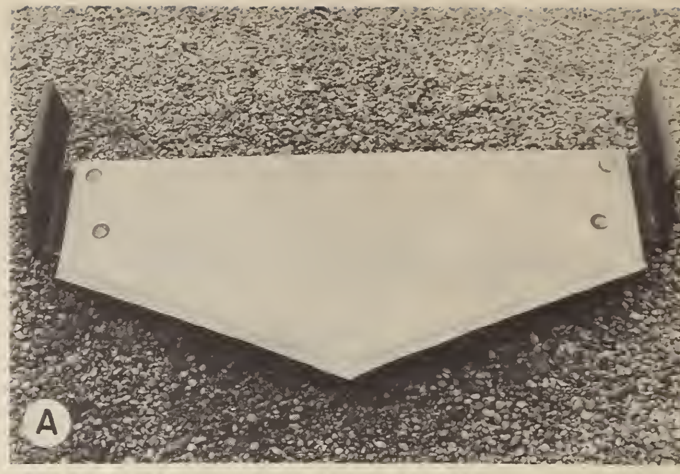
[4] Unpublished reports.

enough to shed fibrous material not severed). Scouring is likely to be better at higher travel speeds than at very slow travel speeds. Where scouring is common, land-polished blades should be protected with a rust preventive when they are not in use. (Stainless steel blades have been used but are expensive.)

Rusty blades should be well polished before use. In soils where scouring persists in spite of all efforts to attain a satisfactory polish on the blade surface, a change in machine design or some other means must be sought for a feasible and economical solution. The first change to try might be to reduce the soil contact area of the share element. This can be accomplished (1) by trimming off some of either the rear edge or the front edge, and resharpening; (2) by cutting slots from the rear edge of the blade straight forward to within 2-1/2 or 3 inches of the front edge. These slots may be from 1-1/4 to 1-3/8 inches wide at the rear, leaving tongues from 1-1/8 to 1-1/4 inches wide between the slots. This reduces the blade area without changing the cross sectional shape of the ribbon mass lifted by the blade, and without changing the angle of the cutting edge against root material. (See figure 1, a and b.)

One blade design recently popular with Red River Valley growers is a slim straight-across blade 2 to 2-1/2 inches wide (fig. 2). This blade has a relatively small soil contact area and scours well when kept sharp enough to cut roots or other materials that tend to hairpin over a dulled edge oriented perpendicular to the direction of travel. In loose soil this type of blade is frequently used with a piece of 1/2-inch pipe slotted on one side and slipped over the entire cutting edge. Fibrous material that is too tough to be cut by the blade sheds over the round surface of the pipe. The pipe can be quickly attached or removed as conditions require.

Both blade sharpness and optimum angle of attack are desirable for cutting fresh or partly decayed fibrous roots or buried plant remains. Two-piece or "open-center" blades have been designed for this purpose. By using a two-piece blade the angle of the cutting edge with respect to direction of travel can be smaller, thus assisting fibrous material to slide along the cutting edge until it is severed or slides off through the center opening or off the outside corners (figs. 3 and 4). To use these open-center two-piece blades, the primary apron frame



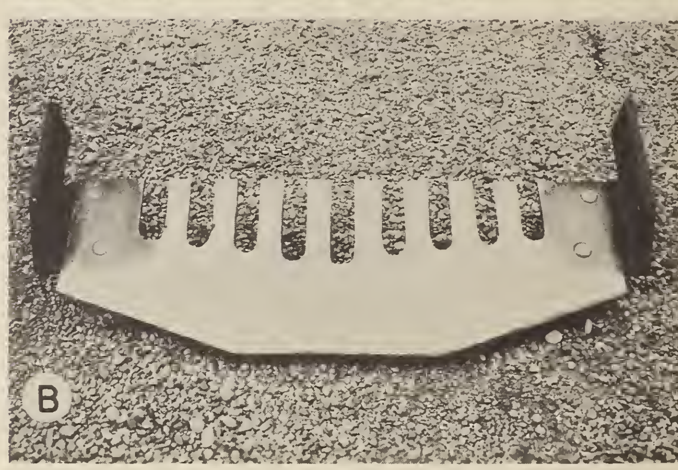


FIGURE 1.--a, Conventional 26-inch harvester blade (actual measurements 25-3/4 by 8-3/4 inches) with a soil contact area of approximately 225 square inches; this blade does not scour satisfactorily in many soil conditions. b, Blade (similar to that shown in 1a) was slotted at the rear and trimmed at the point to reduce the area by 50 square inches. This 22-percent reduction in soil contact area can greatly increase scourability in loose or sticky soil conditions. The cloudy area at each outer corner indicates some scouring deficiency.

must be designed with a forward cross member not far behind the apron idler rollers, as required in using rotary rod blade-substitutes. In some machines, this forward cross member is available only on special order.

Blade-substitutes that function like roller shares in dry soil have been used on many harvesters. These "rounded bar shares" are made by welding a 1/2-inch, 5/8-inch, or 3/4-inch round steel bar on the forward edge of a 3/8- by 1-1/2-inch or 3/8- by 2-inch cross member bolted in the approximate position of a conventional blade. It can be shaped with a drop center to lift the deeper potatoes in the middle of the row and yet lift a minimum of clods from the sides where the soil may have been compacted by tractor tires (fig. 5, a and b).

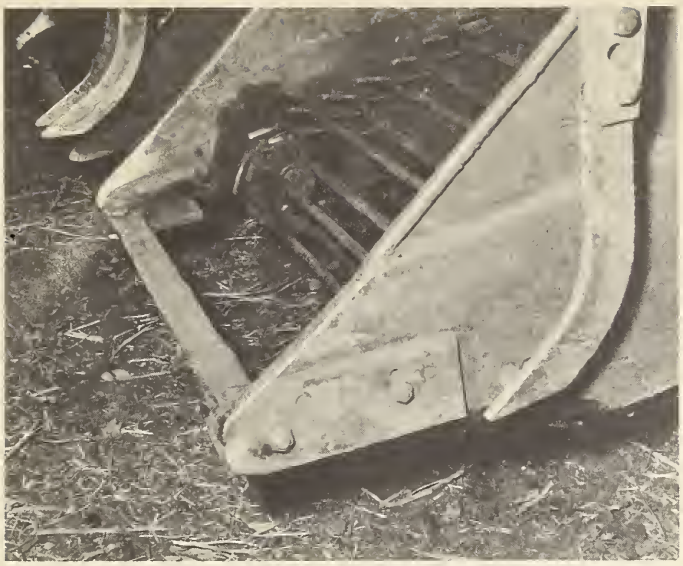


FIGURE 2.--For a sharp share the soil contact area can be reduced to 40 square inches. This blade, approximately 26 by 1-1/2 inches, is practical for use in soil free from stones and other obstructions that impose high structural strength requirements. A variation is to split a 26-inch piece of 1/2-inch pipe and drive onto the forward edge of this share.

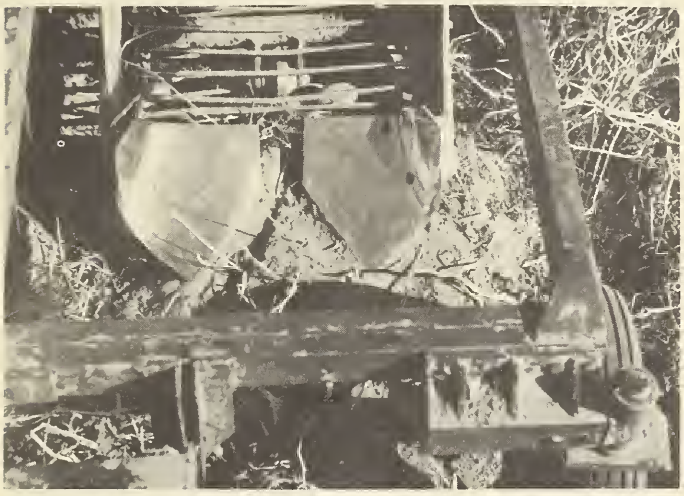


FIGURE 3.--Typical two-piece open-center shares. They require rugged apron frame construction because there is no cross member ahead of the primary apron. Some prefer this type for conditions where tough root materials tend to accumulate uncut on one-piece blades.

These designs have been satisfactory in dry soils but not always in wet, sticky soils. (See figure 5, b.)

Optional use of different types of shares and easy interchangeability deserve serious consideration. In 1961, one manufacturer offered a reversible share that can be used with either a sharp edge or a rounded rod-bar edge forward (fig. 6, a and b).

The range of conditions for satisfactory performance of the rod-bar type of share is not as great as for driven or free-turning roller shares.

FIGURE 4.--Most two-piece or open-center blades have relatively large soil contact areas. They are particularly useful for tough root conditions, but are not practical for very cloddy conditions or for soils with poor scouring qualities.

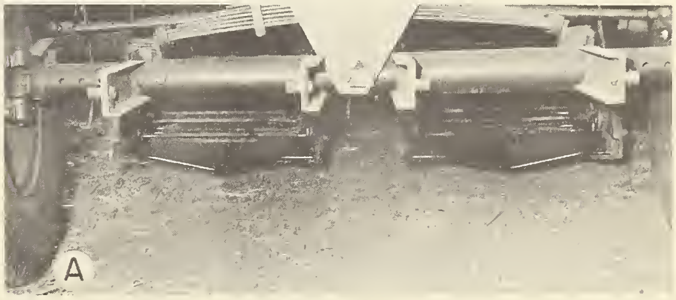


FIGURE 5.--a, Rod-bar type share showing 3/4-inch round rod welded onto the forward edge. Most conditions do not require as much soil contact area for structural strength. b, Under adverse scouring conditions some "hair-pinning" occurs causing spill-out.

Inadequate Apron Speed.--A primary apron speed that is less than the machine travel speed (generally expressed in feet per minute) or that does carry away the loosened material quickly may contribute to spill-out.

The obvious remedy is to increase the apron speed in relation to travel speed

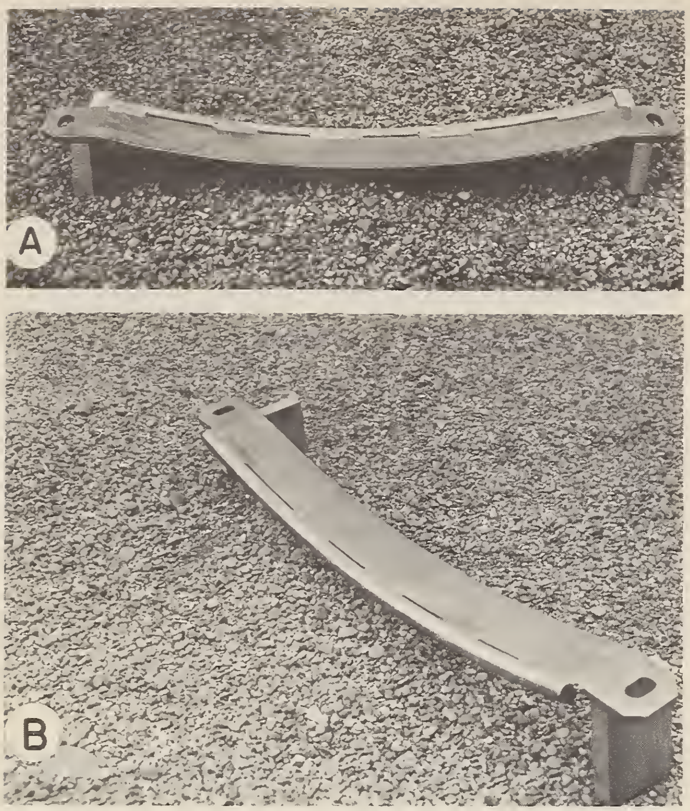


FIGURE 6.--In a reversible share two options can be combined into the design of a single share element by either installing the sharp edge forward (a) or the rod edge forward (b), according to the best use for different field conditions.

until the soil flows onto the apron without an increase in the average depth of the flow ribbon.

Excessive Undersweep.--In very sandy soil or in a dry granular soil much fine soil aggregate sifts through the front of the primary apron and is carried forward again. This recirculation of soil is called "undersweep." Excessive undersweep is often called "boiling" and it affects spill-out in the same way as inadequate primary apron speed.[5]

General Machine Design.--Two-row diggers and harvesters with individual and independently controlled primary aprons are subject to "center spill-out" loss of potatoes through the 8- to 12-inch space between the individual aprons. A twin apron, or "open front" (two 29-inch aprons close together within a single frame) or a triple apron (a narrow apron between two 26-inch aprons) is suggested where there are no compelling reasons against it. Eliminating the space between independent aprons completely eliminates center spill-out and can thus be expected to reduce spill-out by about 50 percent. This design also contributes to machine simplicity and reduces manufacturing cost. Where this change is contemplated, cultural operations should generally be planned to avoid lifting an excessive quantity of clods from the badly compacted middle area[6] between two rows, which will be dug simultaneously.

With the open-front design, and a continuous blade spanning two rows, the edge of the blade must be oriented very nearly perpendicular to the direction of travel. This may subject the conventional blade to hairpinning trouble in light or relatively loose soils, and conversion to a rotary rod share or roller share may be required.

The "open-front" or single apron frame construction may be converted to use a rotary rod share (fig. 7). A single rotating rod long enough to lift two rows (about 63 inches) can be carried by a bearing at each end and one at the midpoint.

FIGURE 7.--The first USDA experimental rotary rod blade-substitute installed in a modified two-row commercial digger. Rod weeder design criteria were used as a guide with the 7/8-inch square rotary rod driven at very low speed with the tractor power takeoff as the source of power.

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[5] For further discussion and suggested ways of correction, see "Increasing Potato-Harvester Efficiency," U.S. Dept. Agr. Handb. 171, 13 pp. 1959.

[6] From tractor wheel compaction during planting and roto-beating or other cultural operations.

Slowly driven rotating rods, oriented perpendicular to the direction of travel and pulled through the soil for tillage purposes, have been used for more than 30 years. Some of these are described in rod weeder patents issued in the early 1930's. In early designs the rotating rod, operating horizontally below the soil surface, was driven through a universal joint and a sloping drive shaft with a sprocket or gear on its upper end. In later designs, known as "center-driven" rod weeders, the rod was mounted in a small sprocket carried in bearings at the lower end of a "boot." This boot also serves as a standard to carry the rod below the soil surface and encloses the drive chain to the sprocket.

The U.S. Department of Agriculture used field-tested components for one of these designs in the Red River Valley in 1955 in the first successful "bladeless potato digger." The idea and its application had been conceived several years earlier by USDA engineers and also by engineers in Idaho and Canada. Experience was cumulated independently in the three widely separated locations under quite different conditions.

Kendell Thornley, a grower in Aberdeen, Idaho, working independently, made a successful application in a two-row harvester in 1955, practically simultaneously with the successful use of the first USDA unit in the Red River Valley.

The design of the first experimental USDA model of the rotary rod blade-substitute in a two-row potato digger was based on commercial rod weeder design. The front apron frame of the original model was replaced with one having a longer radius of swing and its hinge point was moved approximately 14 inches farther to the rear on the main digger frame (fig. 7). USDA engineers subsequently developed another similar late-model two-row open-front digger. Basically similar designs with positively driven rods were developed by two harvester manufacturers and sold as optional accessories for use in muck soils.

The absence of standardized designs in diggers and harvesters made it impossible to devise a standardized design of driven rotary rod blade-substitutes to fit all makes and models. This problem, together with the fact that the power requirement for rotating the rod was found to be relatively low, lead to the study of an unconventional method of driving the rod. It was found possible to deliver the required power through the digger apron.

In 1956, a two-row digger with independent apron frames was equipped with identical rotary rods in each side. The rod on one side was driven through conventional power transmission chains. The rod on the other side was driven by taking power from the apron by two apron sprockets on a shaft inside and near the front of the apron. Although this design increased the total flexing of the apron links and presumably increased the average working tension of the apron on the apron-driven side, there was no increase in wear in the apron links.

After significant success with the first experimental models with the rod positively driven, efforts were made to simplify construction and develop a more nearly universal design. This led to the discovery that the rod could be self-driven when properly mounted in antifriction bearings. Several aspects of design, operation, and comparative performance were investigated. The specifications, pertinent information, results, and recommendations developed are summarized in the following pages.

Certain components cast of wear-resisting white cast iron and field tested in rod weeders were selected for the first experimental USDA design in 1955. These included a driven sprocket to carry a 7/8-inch square shaft, whose symmetrical hubs were carried in very hard white cast iron bearings. Models with these components were custom built in accordance with the original USDA design and successfully used by growers in other parts of the country during 1956 and subsequently.

Before the USDA research was completed, some commercial shops produced other designs that to the casual observer appeared to be similar to the USDA experimental model but were functionally and structurally inferior. They differed in respect to critical or significant dimensions and also in respect to unadapted drive components.

Some disappointments may also have been due to improper adjustments or positioning. A study of these designs and their deficiencies indicated the importance of using an extended pitch chain (No. 2050 1-1/4-inch pitch) with a drive sprocket designed for self-cleaning. This is required to avoid trouble from soil being compacted between

the teeth holding the chain out of normal seating to the designed operating pitch of the sprocket.

Rod Rotation Results

On most standard American farm tractors, when the operator selects a different transmission gear the ratio of rotation of power takeoff driven elements changes with respect to distance traveled. For example, the movement of the digger apron (in feet per 100 feet of travel) is relatively higher when the tractor is operated in low gear than when operated in a higher gear. A similar rule applies when the tractor power takeoff is the source of power for driving the rotary rod.

Following rod weeder design criteria, the power takeoff driven rod in the first USDA experimental design was rotated at the rate of 1 revolution per 18 inches of forward travel or about 67 revolutions per 100 feet of travel when pulled by a Farmall H tractor in low gear.[7] The ratio of rod rotation to travel for operating with the same tractor in second gear was approximately 51 revolutions per 100 feet of travel (with no allowance for tractor drive wheel slippage). In other tests, a nondriven (free-turning) 7/8-inch square rod, carried in ball bearings, showed approximately 44 and 33 revolutions per 100 feet of travel under two soil conditions. Where the 7/8-inch square rod turned 33 revolutions per 100 feet of travel, a nondriven 1-1/4-inch round rod turned an average of 30.4 revolutions per 100 feet of travel. No significant difference in performance was observed within the above range of rotation-to-travel ratio or between the square and round rod shapes. In heavy wet and sticky soils the rotation rate of the nondriven rods was somewhat irregular and there were occasional reversals of about one revolution or less.

All studies of free rod rotation rates were made with a continuous or connected rod across two rows in "open-throat" (twin-apron type) two-row diggers as shown in figure 7. Where conditions gave irregular or erratic undriven rotation, the performance of rods was still satisfactory or at least acceptable. Under similar conditions the performance of conventional-type blades, continuous under two rows, was unsatisfactory because of their failure to cut fibrous material effectively and to scour.

A positive mechanical drive was unnecessary for direct operation under a wide range of conditions but may be desirable or required in heavy wet soils or in very loose, fluffy muck soils. If a rotary rod is used for indirect operation, it is recommended that it be positively driven.

Draft and Rod Torque Results

A number of users of rotary rod units in harvesters in 1956 reported objectionably high draft in very dry conditions. No quantitative draft measurements were made that season. But these reports led to quantitative investigation of draft and rod torque requirements in 1957 and 1958. Soil moisture was high throughout the 1957 season.[8] Tests with a two-row digger in a Beardon series clay loam soil with 25.9 and 30.2 percent moisture content (dry basis) indicated the following:

1. Draft tests in 1957 in very moist soil (moisture content, 30.2 percent) indicated an average total digger draft (two-row digger) of 1,495 pounds with a conventional blade as compared to 1,675 pounds with a 7/8-inch square rod rotating at 67 revolutions per 100 feet of travel. This difference of less than 100 pounds per row was not significant.
2. Draft tests in 1958 under lower soil moisture conditions (moisture content, 23 to 27 percent) showed an average total digger draft (two-row digger) of 1,104 pounds with a blade as compared to 1,767 pounds for a 7/8-inch square rod rotated at 67 revolutions per 100 feet of travel. This indicates approximately 60 percent greater draft with the driven rod than with the blade. At the same time the average draft with the same rod, not driven and not turning, was 1,687 pounds, or 80 pounds less than when rotating. This apparent difference in favor of the nonrotating rod may be due to some unidentified or uncontrolled variable, such as a difference in

[7] A higher rotation rate was used to a limited extent in draft and torque tests in 1957. See discussion of these tests.

[8] The digger used for these tests was basically a two-row John Deere Model 31 used alternately with a conventional blade and with a 7/8-inch square rotary rod, positively driven. (USDA Design No. PB 17.)

depth of operation, which was not precisely measurable.

3. In many other digger draft tests (made with the same two-row digger in cultural practices research) the draft has been highly variable, ranging from 750 to 1,400 pounds in plots of close proximity. The difference was not fully explainable on the basis of known variables.
4. In other studies with rod weeder components in a special field test machine, the draft of standards and "shoes" with and without the 7/8-inch rotary rod, was determined. The draft of three standards with their three shoes only was approximately 64 percent as much as the draft of the complete three-shoe assembly with a 63-1/2- by 7/8-inch square rotating rod driven at 67 revolutions per 100 feet of travel. That is, under these conditions, the draft of the rotary rod only was about 36 percent of the draft of the full two-row rod and shoe assembly.
5. The draft of the rod-carrying standards and shoes only (without the rotary rod) was studied as applicable to two-row diggers or harvesters of independent apron design as compared with twin apron open-front design. The average draft with three shoes positioned as for the open-front design was 967 pounds. The draft with three shoes but with the two outside shoes each set 3 inches farther apart, as would be normal for the design with the two primary aprons independent, was 1,244 pounds. This increase of 138 pounds per shoe, or over 28 percent, was apparently due to operating the two outside shoes in more compact soil 3 inches closer to the center of the tractor wheel tracks.

   Further tests with four standards and four shoes, with the outside shoes in the same operating positions and with the two center shoes 11 inches apart in full simulation of the two-row independent apron design increased the average draft to 1,544 pounds. This is 577 pounds, or nearly 60 percent, more than for the standard and three shoes only, for the twin apron open-front design.
6. The average torque required for rotating the 7/8-inch square rod at the lower (normal) speed (67 revolutions per 100 feet of travel) in soils with a moisture content of 25.9 and 30.2 percent was 801 inch-pounds and 814 inch-pounds, respectively. At a higher speed (123 revolutions per 100 feet of travel) the torque was 740 and 790 inch-pounds, respectively. The combination of very low rate of rotation and the torque in these measurements points to the probability that the maximum power consumed for rotating the rod would seldom exceed 1/8 to 1/4 horsepower per row in any condition.[9]
7. In another series of tests where the soil moisture content was 25.9 percent, increasing the rod rotation from 67 revolutions to 123 revolutions per 100 feet of travel appeared to reduce the total digger draft from 1,700 pounds to 1,475 pounds, a difference of 225 pounds or about 13.2 percent (L.S.D. computed to be 180 pounds, because of high draft variability).[9] It appears logical that increasing the rate of rotation should reduce both rod torque and the resistance of the soil to the forward movement of the rotating rod (net rod draft).

Effect of Rotary Rod on Spill-Out

Spill-out losses with conventional digger blades and with blade-substitutes were compared during three seasons while development work was still in progress and improvements were still being made. Tests during 1958 in Pontiac potatoes showed an average loss of 12.45 cwt. per acre with a conventional blade and 5.36 cwt. per acre with a positively driven 7/8-inch square rotary rod. Tests during 1959 with the same conventional blade, the same rotary rod, and a rod bar blade-substitute in both Kennebec and Pontiac potatoes showed unimportant spill-out losses with a conventional blade, of 0.20 to 0.60 cwt. per acre. No spill-out gleanings were obtained with the conventional blade in 9 of 12 determinations in the Pontiac variety. Spill-out losses with the two types of blade-substitutes were even lower, generally no tubers or not more than one per 150 feet of row per replicate. All losses were less than 0.5 percent of the yield and were insignificant. The completely trouble-free operations and negligible losses were credited to ideal harvesting conditions and a lower-than-normal yield of potatoes in 1959.

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[9] Unpublished data from 1957 annual report.

In 1960, spill-out determinations in Kennebec potatoes with the same conventional blade and the same rotary rod share showed no significant difference. Conditions were favorable and losses were low, 2.74 cwt. and 2.51 cwt. per acre, respectively. In Pontiac potatoes under identical conditions (one of each variety planted simultaneously in paired rows and identical cultural practices), spill-out was significantly lower--1.37 cwt. per acre. There was only a trace of spill-out with the rod; readings were zero for four of six replications. With the blade, spill-out was more consistent and averaged 1.37 cwt. per acre. The observable reason was that the tenacious clinging of the Pontiac tubers to their stolons limited their lateral movement, and practically all were pulled onto the primary apron as an unbroken cluster.

Variability in spill-out appears to occur with variability of yield and, when other factors are constant, may be expected to be greatest where yields are highest. Reduction of spill-out losses and of interruptions to operations caused by unfavorable conditions are both important objectives of improved blades or shares. Both tend to increase or diminish simultaneously with apparent correlation. Serious spill-out is a compelling reason for stopping the machine to clean off the blade and thus correct the trouble. The price of potatoes may determine which of the two losses is more costly. Rates of 50 cents per minute or $35 per hour are often used to compute the value of nonproductive time because of interrupted operations.

Effect of Rotary Rod on Clods

Attempts have been made to devise a method of measuring cloddiness for comparing blades with blade-substitutes. Satisfactory measurements have not been obtained simultaneously with potato harvesting operations where other unidentifiable factors may affect cloddiness. These include (1) compaction of shoulders of the hill during rotobeating or other preharvest cultural operations (caused by tractor drive wheels that are out of proper register with the rows); (2) depth of operation and irregularity in the horizon of a hardpan zone at approximately the same level as the share action.

Harvester operators and others have estimated that clod incidence is 25 to 50 percent less with some of the blade-substitutes than with conventional blades. Precise measurements with improved or special implementation and techniques in cloddy conditions of known uniformity would be required to obtain precise quantitative correlation of clod incidence with blades and with rotary rod shares, roller shares, or other blade-substitutes.

LATEST ROLLER SHARE DESIGN

Because of the wide differences in design of harvesters and diggers, details for the transmission of power to rotate a positively driven rod vary greatly. The location of the rod with respect to the primary apron and certain other specifications should be similar whether it is positively driven or is a free-turning (self-rotating) roller share. Since the latter appears to be widely applicable, a detailed description and specifications for this type only are given here. They are as follows:

Primary Apron Frame Design.--The design of primary apron frames (or apron side plates) varies for different makes of harvesters. Some harvesters are now well suited to use of the latest design of roller shares without special modification. Others are being designed for optional use of roller shares. The principal requirement is the absence or elimination of a frame cross member ahead of the front pair of apron idler rollers (generally cone rollers, if the primary apron is used with the hooks out). Thus the front cross member of the primary apron frame should be to the rear and a little above the front idlers, as indicated in figure 8. For high torsional strength the front cross member should be made of heavy wall pipe or heavy wall oval tubular stock. A tested and practical design of apron side plates and front cross member is shown in figures 8 and 9.

For optional interchangeability with open-center (two-piece independently mounted) blades, the apron side plates should be of mild steel no less than 5/8 or 3/4 inch thick; or the primary apron framing should be strong enough for the open-center blades.

Adapter Plates.--Adapter plates of 3/8- or 1/3-inch mild steel provide for easy interchangeability of different types of shares and for vertical adjustment of roller shares.

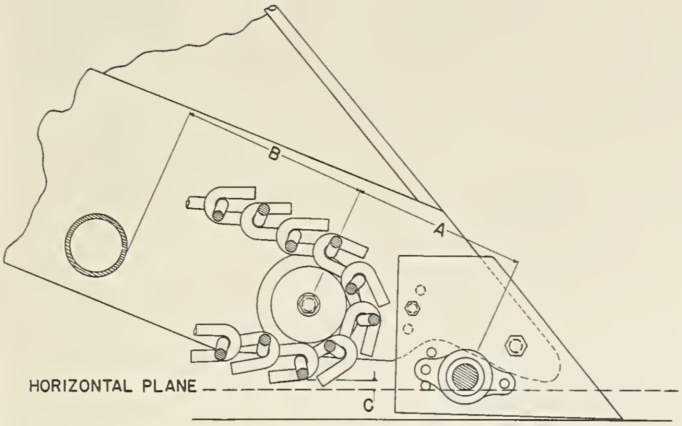

FIGURE 8.--Practical design of apron side plates and front cross member. Dimension "A" should be 6-1/2 to 9 inches, which will provide from 3-1/4 to 6 inches clearance between the roller share and the apron. To operate satisfactorily in very wet heavy soil the distance "B" from the front of the cross member to the center of the front idler should be no less than 7 inches. The apron should operate at a slightly higher level than the lower side of the roller share as shown at "C," which varies slightly with depth regulation. The normal dimension for "C" should be from 1/4 to 5/8 inch.

FIGURE 9.--This commercially designed apron side plate is rugged and can be readily adapted to roller shares or open-center blades. Simple angle iron mounting brackets are required for the open-center blades.

Rod Location.--The location of the rod and frame supporting member in relation to the apron is shown in figure 8.

Rod Shape, Size, and Material.--Smooth round rods are preferable. The diameter for normal service may be either 1-inch high tensile ("stressproof") steel (100,000 p.s.i. minimum yield rating) or 1-1/8-inch cold finished shafting with ends machined to fit the selected bearings. For severe service, use 1-1/8-inch high tensile or 1-1/4-inch cold finished steel. For extra severe service use 1-1/4-inch high strength (100,000 pounds yield point) steel.

Bearings.--When equipped with adequate seals, 3/4-inch Conrad type (nonfilling slot) ball bearings, have proved to be economically practical during thousands of acres of use. Two types of seals that have adequate resistance to lateral soil pressure are Fafnir "Mechani-Seals" and "Plya-Seals". One type of seal found to have inadequate resistance to lateral soil pressures had a thin protective lip of plastic material not supported by an inner shoulder or the face of the inner bearing race. This unsupported lip was flexed inward by the soil which then entered the ball chamber, mixed with the lubricant, and interfered with free rotation. Even with this deficiency some bearing sets gave satisfactory service for 100 acres or more.

Clod Deflector Shovel.--A roller share with a clod deflector shovel (fig. 10) is an optional feature that can be applied to the outside adapter plates as illustrated. Its purpose is to lift compacted soil from the tractor wheel track and deflect it outwardly so that fewer clods will be received on the primary apron. The clod deflector shovel has been tested only one season, but its satisfactory performance to date indicates it should be considered an optional accessory. The dimensions and shape may be subject to some improvement after further testing and experience.

Precautions in Installation.--The dimensions between apron frame members and side plates in harvesters are not usually held to close tolerances. When installing ball-bearing mounted rods, dimensions

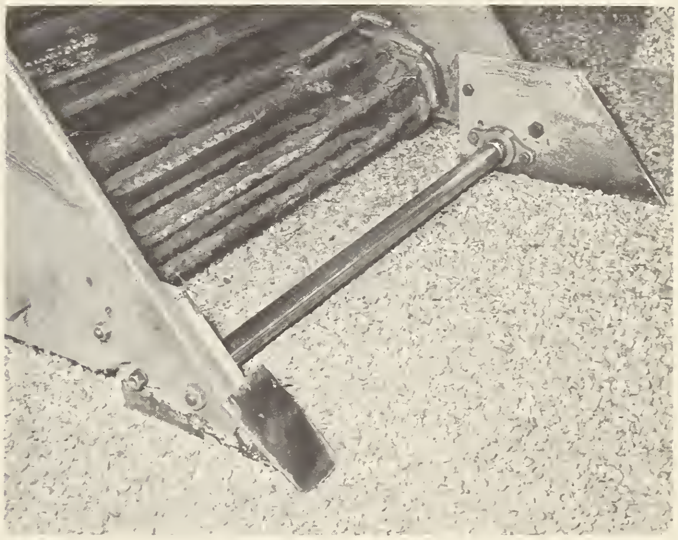

FIGURE 10.--This 1960 roller share, designed and used extensively in the Red River Valley in 1960, gave excellent performance. It uses a 1-1/8-inch diameter stressproof shaft, which for a 26-inch harvester has an active soil contact area of approximately 42 square inches. The small clod deflector shovel is designed to lift compacted soil (from tractor or sprayer wheel tracks) and deflect the clods outside the apron.

should be checked closely to avoid the possibility of end thrust, which could impose an unnecessary or excessive load on the bearings.

Adjustment.--The rod should be adjusted vertically so that when it is operating deep enough to lift all potatoes without crushing, the lower side of the rod will be 1/4- to 1/2-inch lower than the lowest horizontal tangent to the "up" links as they pass under the front apron idler rollers. These positions, once set for the minimum normal operating depth for a machine, should be adequate for a reasonable range in operating depth without further adjustment. If the apron is forced to operate deeper than the lower side of the rod in heavy or compact soil, excessive power consumption and extra apron wear or breakage may occur.

If the share depth is power regulated by double-acting hydraulic cylinders, the mechanical linkage between the power cylinder and the primary apron frame should be designed not only to limit downward movement of the share but also to prevent excessive downward thrust on the share due to inadvertent operation of the control with the machine standing still. (Pressure may be applied through compression springs to assist quick entry to the desired working depth without overstress, which would bend the rod.)

Interchangeability.--Interchangeability between different types of shares should include provision for installing rotary rod blade-substitutes or roller shares. This is being recognized by an increasing number of growers. Various styles of blades or nonrotating type blunt-edged shares can be attached by means of their own adapter plates, which can be bolted inside the apron side plates with provision for adjustability. In this way, shares can be interchanged, and any share assembly can be quickly mounted by means of two or four bolts per unit. Local service shops and some manufacturers are already responding to this demand by growers.

SUMMARY

1. Rotary rods or "roller shares" (driven or undriven) are practical and effective substitutes for conventional blade-type shares for potato diggers and harvesters.
2. Under adverse conditions roller shares can greatly reduce spill-out losses and save more potatoes than is possible with blade-type shares.
3. Roller shares are adapted to a wide range of field conditions and are especially valuable where blades do not scour freely.
4. Benefits are derived in three ways: (1) Reduction of crop losses (by reducing spill-out), (2) more trouble-free operation with a reduction of lost operating time required for cleaning blades fouled with uncut roots or not scouring, and (3) improvement of soil separation because of the crushing action of the thick frontal surface of the roller share which can be 1 to 1-5/16 inches in diameter.
5. Although roller shares have higher draft than freely scouring blades, the difference is generally overbalanced by their crop saving and time saving advantages.
6. Roller shares are now commercially available for several machines through local shops and manufacturers representatives.
7. Undriven roller shares made from high tensile steel shafting compare in price to conventional digger or harvester blades. They cost about $16 per digger row.

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